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Science in the service of society: Is marine and coastal science addressing South Africa's needs?

The modern world is confronted with many and diverse social and environmental challenges of high complexity. In South Africa, rapid and sustainable development is needed to address high levels of poverty and unemployment but this development has to take place in the context of an environment that is already severely impacted by human activities. Sound and relevant scientific input and advice, covering the full scope of each challenge, is essential for effective decisions and actions to address the needs. South Africa has the benefit of strong scientific capacity but the country's National Development Plan reported that national research priorities were not always consistent with South Africa's needs. We investigate the validity of that conclusion in the coastal and marine sciences by examining presentations made at the 2017 South African Marine Science Symposium on the theme of 'Unlocking the ocean's economic potential whilst maintaining social and ecological resilience'. Despite the theme, only 21% of the presentations were judged to be actionable and directly relevant to societal needs, as defined by the criteria used. Less than 7% were evaluated as being interdisciplinary within the natural sciences and approximately 10% were found to include both natural and human sciences. Poor representation by the human sciences was also noteworthy. This preliminary assessment highlights the need for an urgent review of the disciplinary representation and approaches in marine and coastal science in South Africa in the context of the priority practical needs of the country now and into the future.

Significance:

- Despite the urgent need for integrated scientific input and advice to guide responsible and sustainable national development, a preliminary snapshot of marine and coastal science in South Africa demonstrated a low regard for direct relevance and inter- and multidisciplinarity.
- If these general results are verified by a more comprehensive review, urgent realignment of funding and incentives for marine and coastal science, and probably environmental science in general, is likely to be required to ensure science provides a greater service to society, which is the source of much of the country's research funding.

Introduction

The world is facing many near-insurmountable social and environmental challenges that require sound and relevant scientific input and advice if they are to be overcome. In the marine and coastal domains these include ensuring sustainable use of resources and safeguarding biodiversity in the face of widespread poverty, increasing human consumption, climate change, pollution, over-exploitation, infrastructure development and others. At the same time, appreciation of the value of science and therefore support for science globally, including in South Africa, is often fragile.[1] Here we argue that urgent transformation of fundamental attitudes in South African science is required to make it more relevant, appreciated and available for addressing modern-world challenges in the country, in Africa and beyond.

South Africa has a long history of excellence in science and research with many local scientists enjoying international recognition. Research is undertaken and funded by a number of different organisations including government departments, parastatals such as the Council for Scientific and Industrial Research (CSIR), non-governmental organisations and the private sector. We have not investigated the sources and financial contributions of these organisations to research, but the science underpinning South Africa's good reputation does not come without a financial cost. A primary source of funding is the national Department of Science and Technology (DST), which has the mission of 'Increased well-being and prosperity through science, technology and innovation'. The total expenditure of the DST in 2016/2017 was just over ZAR7.38 billion, of which ZAR4.15 billion was spent on 'Research Development and Support', ZAR1.76 billion on 'Socio-Economic Innovation Partnerships' and ZAR1.02 billion on 'Technology Innovation'. Within this total, DST contributed ZAR3.54 billion to the National Research Foundation (NRF), and also contributed funds to the CSIR and other science-related entities.[2] In the same financial year, 2016/2017, the total expenditure of the NRF was ZAR4.51 billion, of which nearly ZAR2.7 billion was for Research and Innovation Support and Advancement and the Technology and Human Resources for Industry Programmes.[3] It must be recognised within the context of this paper that only small fractions of these amounts would have gone into marine and coastal research and that other government departments and state-supported entities also fund such research. The taxpayer and public in general are major contributors to research undertaken and funded by governments and parastatals and it is therefore reasonable to ask if the country is getting a worthwhile return for its investments in science.

It is necessary to consider this question within the local context. South Africa is ranked 119th in terms of its Human Development Index, making it one of the 'medium human development' countries.[4] The Human Development Index incorporates national mean life expectancy (57.7 years) and a mean gross national income per person (USD12 087). However, income per capita is heavily skewed; in 2015 there were over 30 million South Africans living in poverty (on less than ZAR992 per person per month). Unemployment in 2016 stood at nearly 27%.[5]

The needs for economic and social development to overcome these problems are enormous and urgent but they must be remedied in a sustainable way that does not prejudice the resources and environmental potential and opportunities in the future. Science and technology are critical for guiding and informing equitable and sustainable development but

South Africa is not doing very well in this regard either, and in 2015 the country invested only 0.8% of its gross domestic spending on research and development (conducted by all resident companies, research institutes, university and government laboratories, etc.), putting it 37th out of the countries reported on and far behind countries such as Korea (4.2%), Germany (2.9%) and China (2.1%). Malaysia and Brazil spend approximately 1.3% of their GDP on research and development.[6]

Marine and coastal ecosystems and resources provide essential livelihoods and services for hundreds of thousands of people in South Africa. The wholesale value of the marine fisheries sector in South Africa in 2016 was more than ZAR10 billion[7] and about 27 000 people are directly employed in the commercial sector alone[8]. Tourism centred on the oceans and coasts, shipping, offshore oil, gas and mining operations and other sectors provide employment and livelihoods to tens if not hundreds of thousands more. There is also pressure to expand and it has been estimated that South Africa's oceans could contribute as much as R177 billion to the country's gross domestic product and provide between 800 000 and 1 million jobs by 2033.[9]

The need for sustainable development and biodiversity conservation are recognised in South Africa's Constitution, which states that the environment must be protected for the benefit of present and future generations and that development must be ecologically sustainable (Constitution of the Republic of South Africa[10], Chapter 2, paragraph 24). However, the current and historical uses of the marine and coastal zone have put the environment under considerable stress. For example, the 2011 National Biodiversity Assessment[11] concluded that 43% of estuary ecosystems were threatened (39% critically endangered); 58% of coastal and inshore ecosystem types and 41% of offshore marine ecosystem types were considered threatened (24% and 11% critically endangered, respectively).

For resource management and conservation to be more effective and ethical, it must better engage the economic, political and sociocultural dimensions of humans as part of ecosystems.[12,13] Achieving the desired goals requires timely, reliable and relevant scientific information and advice, as emphasised in the National Development Plan (NDP)[14], which also warns that 'Despite an excellent set of science institutions, research priorities are not always consistent with South Africa's competitive advantage or growth strategy.'

What research priorities are required to serve society?

There is no simple way to define the research priorities that would best meet the needs of a developing South Africa, or of the world as a whole. Research needs will depend on the nature, problems and opportunities specific to each case. The approach of science and scientists to setting priorities can be divided into two models.[15] The first is the 'linear model', which emphasises basic research with limited consideration of the potential flow into application for societal benefit. Under the linear model, if potential relevance is a consideration, the scientist will envisage a flow from basic to applied research and then on to application.[15] The second model is the 'stakeholder model' in which the potential users of the research are involved in its design and production and the role of science in decision-making is an important consideration. The linear model can potentially lead to valuable application but we argue that the stakeholder model provides a more participatory and effective approach to ensuring relevance and maximum impact of the science, which are important considerations, especially in a resource- and capacity-limited country like South Africa.

A further aspect that must be considered when assessing the likely impact of science is the extent to which specific research considers or contributes to addressing the full scope of the problem or question. Many of the most intractable challenges that confront us today are complex social-ecological problems such as addressing climate change, the conflicts between development and environmental sustainability, over-exploited fish stocks, competition between different user groups for scarce resources and others. The South African small pelagics fishery serves as an example of the complexity of challenges such as these (Figure 1). Nevertheless, reductionist approaches to science, in which a complex scientific problem is broken down into simpler components, addressed individually, remain the predominant approach to science.[16] Reductionist science unquestionably has its uses but it is increasingly clear that isolated reductionist studies are insufficient for many of today's complex challenges. Karl Popper, a leading philosopher of science in the 20th century, wrote:

> *But this classification and distinction* [into disciplines] *is a comparatively unimportant and superficial affair. We are not students of some subject matter, but students of problems. And problems may cut right across the borders of any subject matter or discipline.*[17]

The response to these awakenings has been a growing demand for and engagement in interdisciplinary and transdisciplinary science.[16,18-21] This growth has been attributed to four drivers: (1) the need to solve societal problems; (2) the intrinsic complexity of social-ecological systems;

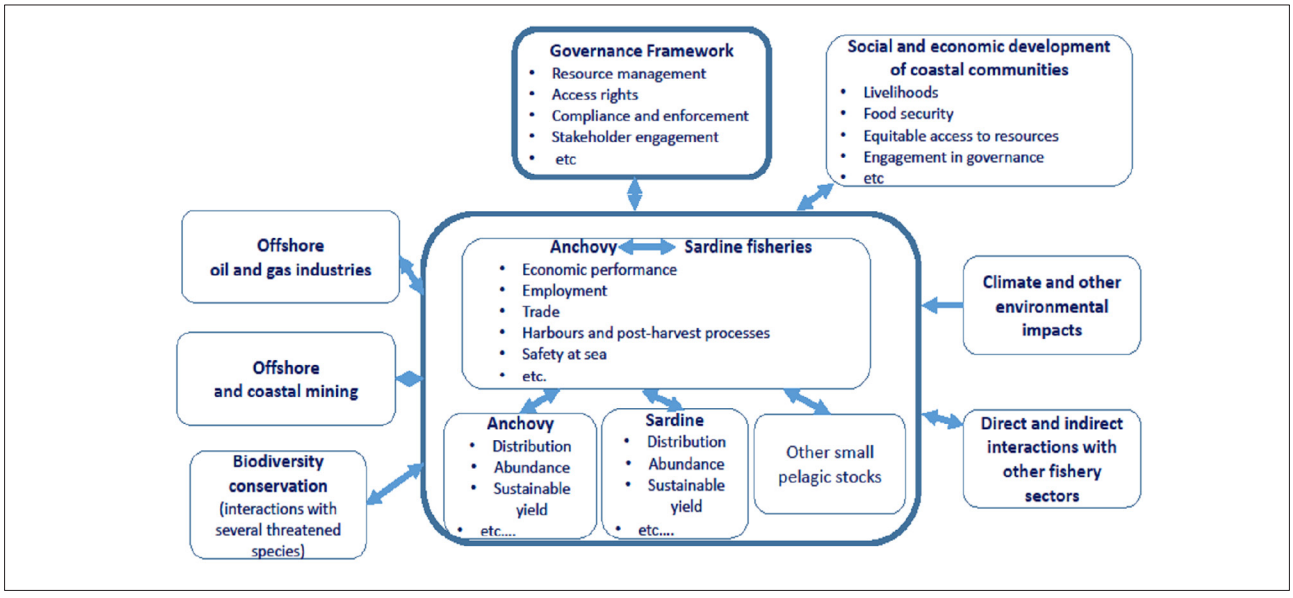

Figure 1: Simplified representation of an example of an integrated social-ecological system that needs to be managed as such: the South African fishery for small pelagic species. The boxes outlined in bold show the components of the core system and external drivers and stakeholders are shown outside the bold boxes.

(3) a desire to investigate issues beyond disciplinary boundaries; and (4) the capabilities of new technologies.[19] The first two are particularly relevant to South Africa while the second two can be seen as factors that should facilitate a shift towards interdisciplinary approaches.

Within this context, we undertook a preliminary assessment, within the field of coastal and marine sciences, of the validity of the concern expressed in the NDP about the disparity between the research priorities required for growth and development in South Africa and those being pursued in practice.

Methods

Scientific research in the marine and coastal environment in South Africa takes place in a number of universities, government departments, specialised research institutes such as the CSIR and the South African National Biodiversity Institute, non-governmental organisations and others. Outputs are published across a wide range of media types. It would be a massive task to survey all the bodies undertaking research and their outputs, and beyond the scope of this study. We therefore took advantage of the 2017 South African Marine Science Symposium (SAMSS) as providing a snapshot of current research in the field. SAMSS is an important biennial event in marine science in the country that aims to bring together local and some international marine and coastal scientists to present their work and exchange ideas. The theme of the 2017 event was 'Embracing the blue. Unlocking the Ocean's economic potential whilst maintaining social and ecological resilience'[22], which would appear to be particularly pertinent to this assessment of the relevance of South Africa's coastal and marine science to meeting social, economic and environmental goals and challenges.

Presentations at the symposium were divided into oral, speed (short oral presentations) and poster presentations. We focused on the oral and speed presentations on the assumption that they would be the more likely to include work from the established scientists and research that was already underway. Abstracts for the 102 oral and 80 speed presentations delivered at the symposium were assessed. The abstracts are available from the Congress Book on the Sancor website[22] and those related to oral and speed presentations can be determined from the programme, which is included in the Book. Alternatively, the PDF documents containing the abstracts already grouped into oral and speed presentation, downloaded from the no-longer available original symposium website (www.samss2017.co.za), are available from us on request. Each abstract was categorised according to the main discipline or theme covered and whether it was multidisciplinary or interdisciplinary in nature.

Disciplines and themes (listed in Table 1) were identified from examination of the abstracts and are intended to provide a general classification giving an indication of the scope of the presentations as a whole and areas of concentration. This approach means that not all disciplines in the natural and human sciences are included in the list. The categories range from conventional disciplines such as zoology and botany to broader categories going beyond traditional disciplinary boundaries, such as conservation of biodiversity and socio-economic development. The boundaries between botany and zoology on the one hand, and ecology on the other, are not always clear. For the purposes of this assessment, only studies that considered the ecology of several species or of systems as a whole and that included more than one natural science discipline (e.g. zoology and oceanography) were classified as ecology. We recognise that other, equally defensible, criteria could be used for this purpose that would produce different breakdowns and potentially higher representation of ecology as a discipline at the symposium.

The definitions of multi- and interdisciplinary research used were[19]:

> *Multidisciplinary: research that involves more than a single discipline in which each discipline makes a separate contribution;*
>
> *Interdisciplinary: research that 'integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice'.*

The broad interpretation of multidisciplinary used in this assessment (Table 1) means that, for example, ecological research would normally be judged to be multidisciplinary because it involves biology (botany or zoology) as well as, for example, physics, chemistry and/or geology. In contrast, interdisciplinary studies require 'an integration and synthesis of ideas and methods' across two or more disciplines.[19]

Table 1: Guidelines and criteria used in classifying abstracts

Category	Guidelines	Notes and references
Main discipline or theme	Eight categories were applied: zoology; botany; ecology; oceanography; geology/geochemistry/geophysics; conservation of biodiversity; fisheries; socio-economic development (general).	In some cases, abstracts could have been classified under more than one discipline. In such cases the authors selected the option that they considered best fitted the abstract as presented. Further details are provided in the text.
Multidisciplinary	A broad interpretation of the definition was applied and included any study that made use of information from more than one discipline, even if only attempting to advance knowledge in one of them. The results therefore provide a somewhat optimistic result on incidence of multidisciplinary research.	US National Academy of Sciences[19]
Interdisciplinary science: split into either (1) within the natural sciences or (2) including both natural and human sciences	For (1) within the natural sciences, consistency with the US National Academy of Sciences definition[19] and for (2) consistency with the US National Academy of Sciences definition AND encompassing both natural and human sciences.	US National Academy of Sciences[19]. Our purpose with category (2) was to identify research that encompassed social-ecological systems as a whole.
Actionable and relevant to societal needs	(1) Clear and explicit links to practical application and benefits, including indication of the agencies or stakeholders through which this will be done; and/or (2) Abstracts need to demonstrate consistency with the 'stakeholder model' of science.	(2) Pielke[15]. Unsubstantiated and/or vague statements in an abstract that the research will be of benefit were not accepted as sufficient justification.

We did not attempt to distinguish between interdisciplinarity and transdisciplinarity[18] but recognise that both are important.

Finally, we considered whether the abstract fulfilled the criteria for being applied and directly relevant to priority societal needs. Research that fulfils those criteria is described here as being *actionable science*[23,24], which can be defined as:

> *Science that is relevant and/or applicable to government, business, and non-governmental organisational (NGO) audiences, and, in its broadest sense, can inform a larger, interested public. It is scholarship with the potential to inform decisions within government, business, and households; improve the design or implementation of public policies; influence public or private sector strategies; and inform planning and behaviors that affect the environment.*[25]

The term 'actionable science' is introduced and used in this paper in preference to the more general term 'applied science' because the former places particular stress on direct application and support to stakeholders, both of which are needed for growth and sustainable development in South Africa, as argued above. The specific criteria used for categorising the abstracts are provided in Table 1.

Results

Approximately 670 authors were listed in the abstracts for the oral and speed presentations. They included individuals from a number of different countries but the large majority were from South African entities. Without adjusting for duplications where individuals were authors of two or more presentations, and covering all countries represented, approximately 59% of authors gave their primary (first) affiliation as being a university, 18% as a national institution (partly or fully funded by the state), 13% as a government department, 3% as a provincial institution or government department, 1% as an NGO and approximately 6% were unknown.

The presentations were overwhelmingly dominated by the natural sciences: over 40% of the 182 oral and speed presentations were classified as being in the field of zoology, followed by ecology making up 13% of presentations. The relative contributions of zoology and ecology are dependent on the criteria used to distinguish them and, as discussed under Methods, different but equally defensible criteria could produce considerably different results on the split. Nevertheless, whether classified as zoology or ecology, presentations within the general field of zoology were dominant. Conservation of biodiversity was the third most common discipline or theme making up 10% of abstracts (Figure 2). A total of 12 presentations (7%) were classified as being in the field of socio-economic development but not all of those could be described as falling within the human sciences, for example reviews of the role of research programmes or specific disciplines in promoting economic development. Most presentations in the other two functional categories, fisheries and conservation of biodiversity, addressed natural science aspects.

Approximately 35% of the abstracts were judged to be multidisciplinary, using the generous interpretation described in Table 1. These abstracts were all within the natural sciences and no abstracts were identified that could be considered as falling within a conventional human science discipline (e.g. sociology, economics) or that involved two or more discrete human sciences (i.e. multidisciplinary). Most abstracts classified as socio-economic development were classified as being interdisciplinary. Overall, less than 7% of abstracts were evaluated as being interdisciplinary within natural sciences and approximately 10% of the presentations was found to encompass both natural and human sciences in an interdisciplinary manner (Figure 3).

The result that should arguably be of the greatest concern is that only 21% of the presentations, 38 out of 182, were judged to be actionable and directly relevant to societal needs, as defined by the criteria provided in Table 1.

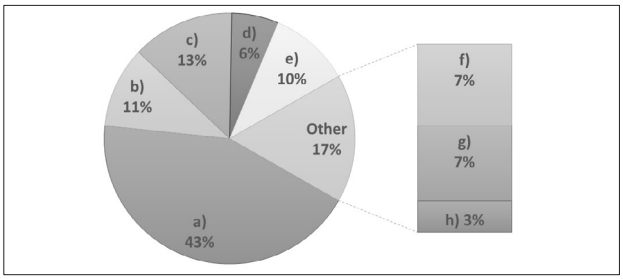

Figure 2: Percentage of presentations (n=182) according to discipline or theme: a) zoology; b) botany; c) ecology; d) oceanography; e) conservation of biodiversity; f) fisheries; g) socio-economic development (general); h) geology/geochemistry/geophysics.

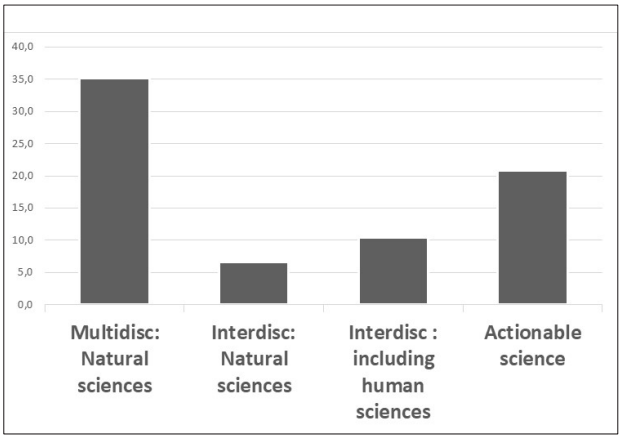

Figure 3: Percentage of presentations (n=182) that were multidisciplinary (Multidisc) or interdisciplinary (Interdisc) and that were assessed to be presenting actionable science.

Discussion

We acknowledge that examination of the oral presentations at a single event provides only a limited and incomplete snapshot of marine and coastal science in the country, but note that SAMSS is the premier national symposium for coastal and marine science in South Africa and can be assumed to have provided a reasonable sample of the leading science in the field across a range of institutions. It can also be argued that the abstracts do not always provide sufficient information for accurate application of the criteria but the abstract is intended to provide a concise overview and we took care to apply the criteria objectively and rigorously. If the research being undertaken was directed at contributing directly to addressing an identified societal need, it is reasonable to assume that this would be referred to in the abstract.

Overall, there will have been an element of subjectivity and potential for error in the categorisations and we consider the results to give only an approximation of the true situation but with the trends being sufficiently marked such that the potential error is unlikely to change the overall picture. The results presented here should therefore be of concern to all scientists, clients of science and funders of science in the country, particularly if one also takes into account the strongly applied, interdisciplinary theme of the 2017 event. If presenters and their co-authors had even noticed this theme, one could have expected the programme to be marked by actionable, interdisciplinary science, which clearly did not happen. Hence, while the banners of application and interdisciplinarity are frequently paraded around to try to accommodate for ongoing trends in science, scholarship and funding globally, true actionable and interdisciplinary research in South Africa appears still to be of limited popularity amongst the marine and coastal scientific community.

Comment must be made on the very poor representation by human sciences in the presentations. It seems clear that SAMSS is largely

perceived to be a natural science symposium and therefore that not much can be concluded from the SAMSS programme about the societal relevance of humanities in marine and coastal research or the engagement of human scientists in interdisciplinary research. One primary cause of the poor representation must be the lower number of human science practitioners in this field in South and southern Africa compared to natural scientists but that is not the only cause. Another important reason, and factor contributing to the lower number of social scientists, is a long-ingrained bias towards the natural sciences that pervades environmental conservation and management in general, including amongst managers of governmental institutions with a mandate for these tasks[21,26], notwithstanding the fact that the scientific advice is sometimes overruled for supposedly social or economic reasons. This bias towards the natural sciences creates substantial barriers in the responsible institutions and practices in marine resource management in South Africa, and globally, to greater involvement of the human sciences. These barriers apply particularly to the social sciences, including human ecology and geography, behavioural psychology and political ecology.

Factors within the human sciences also play a role and, based on our own experiences and interactions with researchers in the humanities, our perception is that there is a bias in South African social science and humanities towards engaging mainly in humanistic (post-modern, reflexivity, critical theory, etc.) academic debates around identity, race and gender. While important in themselves, these issues are of limited direct application to managing and conserving regional marine environment and resources. This raises the question of why so few social science and humanities scholars are studying fishing communities and the ecology of human-environmental interactions when this knowledge is so important for the well-being of both social and natural systems? We argue that an important reason is because contemporary humanities training, which is dominant in both northern and southern hemisphere universities, has a strong anti-science emphasis. Humanities have been challenging northern-dominated conservation models and science in general[27,28], and while such criticism is generally valuable, the growth of other empirical environmental social and behavioural sciences such as human ecology are fundamental to create a better link between the natural and social sciences. It is our view that scholars working in the humanities need to reform their discourse vis-à-vis natural scientists because today many have managed to marginalise their role[29], including by being unable or unwilling to relate to or communicate with natural scientists[30]. Humanities scholars are likely to reject the suggestion that they should change their discourse to match the agendas of natural scientists but this means that, sadly, many humanities scholars are engaged in abstract debates when the South African marine environment is being degraded at an unprecedented rate, contributing to the impoverishment of many of the same subjects that they study and which they want to liberate from poverty.

An additional, likely cause of low engagement of the human sciences in holistic interdisciplinary science and in stakeholder models of applied and actionable science is that the general academic drivers and incentives that lead to low engagement of natural scientists play a role with human scientists too.

This preliminary assessment highlights the need for a review of the disciplinary representation and approaches in marine and coastal science in South Africa in the context of the priority practical needs of the country now and in the future. The primary developments, threats and opportunities for coastal and marine environments and resources and the scientific information and advice most needed to address them should be identified. For example, Operation Phakisa[9] identified seven oceans economy focus areas that included offshore oil and gas, aquaculture, coastal and marine tourism and marine protection services and governance, to which should be added other areas of social and economic importance such as fisheries, conservation and coastal development. What types of scientific support are required to ensure sustainable, responsible and productive development or maintenance of all of these areas and how does that compare to the research status quo?

We recognise that pure science has a place in society[31] but the most pressing and alarming of the results must be the low incidence of presentations assessed to be directly relevant and actionable in addressing societal needs. We agree with the opinion expressed in a 2014 publication by McQuaid[31] that 'South Africa should aspire to being a nation that values science for its own sake' but also with his view that 'society can and should put demands on science' especially given the important and urgent social needs within the country. The key question for all engaged in science in the country, and at least other developing countries, is to find the appropriate balance. The results shown here suggest that society in South Africa has good cause to expect more practical support from science than it is receiving at present.

Similarly, high quality disciplinary science is frequently necessary in provision of scientific guidance to practical questions and problems but is rarely sufficient on its own. Disciplinary science should therefore not be discouraged but much greater emphasis must be placed on development of interest and capacity in interdisciplinary science to enable pressing, complex questions and problems to be addressed in the holistic and integrated way necessary for successful impact.

Overall, the indications from these results are in stark contrast to the missions of the DST: 'To provide leadership, an enabling environment and resources for science, technology and innovation in support of South Africa's development'[2] and the NRF: 'Catalysing knowledge production for societal benefit'[3]. It is a safe assumption that other governmental and parastatal organisations that contribute significantly to marine and coastal research in South Africa, including the Departments of Agriculture, Forestry and Fisheries and of Environmental Affairs, as well as the CSIR, are also mandated to focus on provision of sustainable benefits to society. We did not look at the performances of specific organisations against the criteria but our results demonstrate that, while some actionable science is indeed achieved, in practice much of the marine and coastal science being undertaken in South Africa is not being very effectively targeted at achieving these societally oriented missions.

The reasons behind the weaknesses identified here are complex but we suggest that a fundamental problem must be the incentives that drive scientific careers. One such incentive is the NRF rating process and standards. The NRF's rating criteria (http://www.nrf.ac.za/rating) put emphasis on 'high quality research outputs', which in practice is interpreted primarily as number of papers in the primary scientific literature and citations. We are all B-rated scientists, signifying recognition as 'internationally acclaimed researchers', but are of the firm opinion that these indicators do little to encourage attention to practical implications or interdisciplinary science and probably act more as an incentive for fragmented and 'clean' disciplinary approaches. In our view, the NRF needs to revisit its rating process and other funding instruments to ensure their outputs and outcomes are consistent with its mission and national needs.

The problem is of course much wider than NRF ratings and stems from a long history of reductive thinking and a culture-driven belief that pure science is more worthy than applied (and by implication actionable) science.[16,32] The obvious limitations of this outdated philosophy highlight the need for transformation in science in South Africa and globally so as to recognise and give priority, not just to excellence in science, but to the societal value of actionable science, particularly the science supported and facilitated by the general public through tax and other inputs.

Recommendations

The difficulty of breaking down the prevailing dominance of reductive, disciplinary-based thinking is not limited to South Africa and remains a global problem, but internationally there has been significant progress towards a greater role for holistic, interdisciplinary science in the scientific agenda.[16,19,20,33] For South Africa to ensure that our science is both relevant to the needs of the country and competitive with the latest and best of scientific practices internationally, we recommend:

1. NRF and DST should undertake a first assessment of the current and future needs for scientific research (natural, human and interdisciplinary) to advise and inform the development and use of the social-ecology of the country. This first assessment could be based on already available information, for example, from the

NDP and Operation Phakisa. Here we have addressed only coastal and marine science, but the exercise could usefully be expanded to include environmentally oriented science in general.

2. The first assessment undertaken could subsequently be taken further and finalised through a thorough review conducted in consultation with relevant stakeholder groups including but by no means limited to scientists.
3. Using the first assessment of needs as a starting point, DST, NRF, all tertiary educational and research institutions, and government departments and agencies engaged in environmental governance and research should, through a formalised and peer-reviewed process, urgently review their research and teaching activities and recent outputs in the context of the identified needs.
4. Thereafter, if the results from (3) indicate a substantial disparity between national needs and research activities and outputs, government and the private sector need to ensure that the necessary incentives and pressures are put in place to bring about rapid transition, wherever required, to ensure that resources being put into science are leading to optimal returns for the country as a whole. A simple example of such an incentive would be for government agencies to introduce funded calls for research projects or programmes specifically aimed to address clearly defined and pressing marine and coastal societal needs, and then to ensure that the funded research is adjudicated accordingly.
5. Ensuring the societal relevance of science and research will bring about benefits but must be accompanied by an increase in expenditure on actionable research and development to help to address the multiple and urgent social, economic and environmental challenges that need to be met and to facilitate achieving the goals of, for example, the NDP[14] and Operation Phakisa[9].
6. The changes required will almost certainly include a greater emphasis on interdisciplinary science and integrated, holistic approaches. Urgent priority therefore needs to be given to developing the capacity to meet that need. This requires producing and nurturing qualified practitioners in interdisciplinary science but also ensuring that disciplinary specialists are trained to be able to see beyond the silos of their own disciplines[34], to recognise how their expertise can contribute to wider programmes and to be open to working in interactive ways as members of multidisciplinary teams.
7. It is not within the scope of this article to suggest how to increase the number of qualified interdisciplinary scientists and the awareness of the need for interdisciplinary science in marine and coastal use and management but useful ideas can be found in the report 'Facilitating Interdisciplinary Research'[19] produced by the US National Academy of Sciences.
8. The benefits of the above steps will only be realised if the available and relevant scientific advice is actively solicited, welcomed and used wisely and effectively by the stakeholders, including government. This has not always been the case in the past and, for example, decisions in recent years by the Department of Agriculture, Forestry and Fisheries to exceed scientific recommendations on the total allowable catch of the already seriously depleted West Coast rock lobster *Jasus lalandii* resource[35] give cause for concern. Every effort should be made to ensure that decisions and actions taken by government departments and other stakeholders are based on the available scientific evidence, also taking into account, as appropriate, additional knowledge. This is essential if the Constitutional obligation for ecologically sustainable development is to be realised. In addition, government itself, not only in South Africa but globally, needs to overcome the common tendency to pursue sectoral and vested interests and, instead, to adopt sustainable integrated approaches.[26,36] It is hoped that the 2017 Marine Spatial Planning Bill[37] indicates a movement in this direction for governance of the nation's oceans.

Finally, the quality and reliability of actionable and interdisciplinary science are at least as important as in any other fields of science, and scientists, funders and users of marine and coastal science need to ensure and insist on scientific rigour in design, implementation and interpretation. As in so many other areas, the unique characteristics and diversity of South Africa and its people mean that South African science and scientists could provide innovative leadership in forging new models and paradigms in science for development and sustainability.

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Authors' contributions

K.L.C. was the lead author, and took the lead in all aspects of the study, including conceptualisation, development of the methodology, collation and analysis of data and writing of the initial draft and revisions. W.H.H.S. and S.A. made substantial contributions to conceptualisation, development of the methodology and writing of the initial draft and revisions. W.H.H.S. also contributed substantially to the collation and analysis of the data.

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